Design and analysis of liquid metal EUV collector mirrors using the Zemax ray tracing code

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1. Abstract

Focusing 13.5 nm light requires mirrors that are essentially atomically flat. Maintaining this high level of finish in front of a hot, debris producing, tin plasma is proving extremely difficult for extreme-ultraviolet (EUV) source manufacturers. Our solution is to apply a thin coating of a liquid metal to the inside of a solid collector mirror shell, as the surface of clean liquid metals is atomically flat. This liquid metal, a tin alloy, is chosen as a compromise between EUV collection efficiency and low melting point. In parallel with the experimental characterisation of simple liquid metal collector optics, we have used the commercial ray tracing package Zemax [1] to model, analyse and assist in the design of liquid metal based EUV collector systems. We will continue to use Zemax throughout this research to define optimal mirror shape and size for particular EUV sources and particular EUV output powers depending on the application. Here we present an overview of the modelling work to date.

2. Introduction

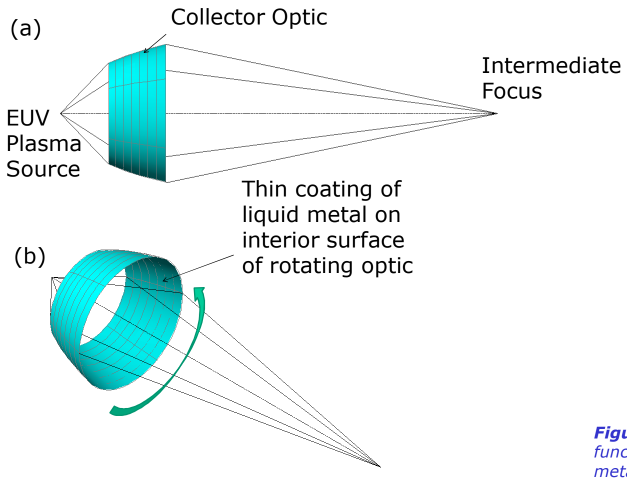

Figure 1: *Schematic of rotating liquid metal mirror (a) side view (b) isometric view*

Key features of liquid metal collector mirrors

- Liquid metal made of the same metal as the plasma fuel.
- Particles or ions impinging on and sticking to the mirror surface will flow into the liquid mix, maintaining the ultra flat finish required.
- Liquid mirrors will provide much longer lifetime than current state of the art solid mirrors and remove or reduce the need for debris mitigation before collector.
- Significantly cheaper to produce than current state of the art solid mirrors.
- Challenge is to find a flow regime in which the surface is stable enough to deliver the required mirror figure.

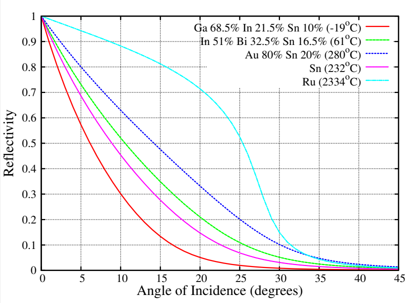

Figure 2: Theoretical reflectivity curves of various liquid metals as a function of grazing incidence angle at 13.5 nm [2]. Melting point displayed in brackets.

3. Zemax Modelling

Equation of 2D ellipse is given by: $\frac{x^2}{a^2}+\frac{y^2}{b^2}=1$

Ellipse focal length, F = a*Ɛ, where $\varepsilon=\sqrt{1-\frac{b^2}{a^2}}$

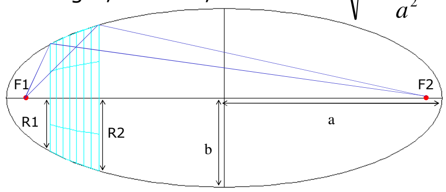

Figure 3: *2D ellipse parameters, where a and b are the semimajor and semiminor axes , respectively. All lines originating at first focus, F1 are brought to a focus at F2.*

Ellipse section completely defined in Zemax by four parameters:

(1)Radius of curvature = $\frac{b^2}{a}$
(2)conic constant = - ε^2
(3)Small aperture radius, R1
(4)Large aperture radius, R2

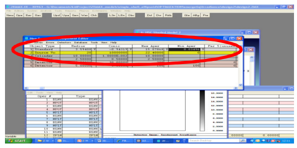

Figure 4: *Zemax user interface showing lens data editor (circled).*

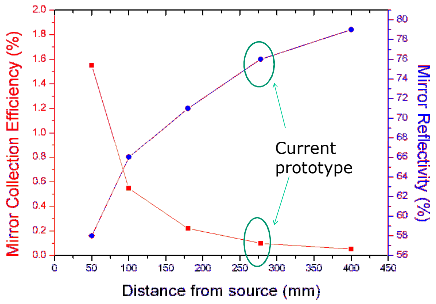

Figure 5: *Mirror collection efficiency and reflectivity as a function of distance from source, for an 80 mm long, liquid metal (Galinstan) coated mirror section. The ellipse parameters are those used for the ellipsoid prototype currently under test in the lab. Source size is 100 μm.*

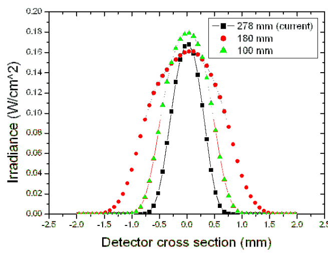

Figure 6: *Image cross sections for 3 different mirror sections of Fig. 5. Source is uniform spherical of diameter 100 μm and power 1W (into 2 π steradians).*

3.1 Optimization of single shell ellipsoid

Optimization targets: (1) Maximise flux (W) at image plane
(2) Minimise RMS spot radius

Variables: (1) Radius of curvature
(2) conic constant (effectively eccentricity)
(3) Large and small aperture diameters

Fixed Parameters or constraints: (1) Mirror length = 100 mm
(2) Large aperture diameter < 100 mm
(3) Source to mirror distance fixed

Optimization results for typical commercial DPP source:

	Present Collector	Optimized Collector I	Optimized Collector II
In-band Power at source (W)	11.2	11.2	11.2
Source radius or FWHM (mm)	0.345	0.345	0.345
Power Density at Source (W/mm²)	30	30	30
Source to mirror distance (mm)	278	200	25
Image size FWHM (mm)	4.7	1.1	0.9
Magnification	13.6	3.2	2.6
Transmission / Power into FWHM (mW)	7.0	13.7	96.6
Average Reflectivity (%)	78	67	18
Power Density at Image (mW/mm²)	0.4	14.4	151.9

4. Ongoing work

- Use Zemax tolerancing to calculate the substrate machining tolerance.
- Optimize mirror shape for different liquid metals.
- Design more complex optics e.g. Wolter type.

5. References

[1] *http://www.zemax.com*
[2] *http://henke.lbl.gov/optical_constants/mirror2.html*

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